Multi-technique Studies of Ionospheric Plasma Structuring

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LONG-TERM GOALS

Understanding physical processes that leads to plasma structuring in the equatorial, mid- and high-latitude ionosphere. Identifying the effects of such variability, generally known as ionospheric space weather, on the operation of various communication, navigation and surveillance systems.

OBJECTIVES

Establish major drivers that lead to structured ionospheric plasma in equatorial, mid and high-latitude regions. Investigate cascading of plasma structuring from large (~ hundreds of km) to small (~ tens of m) scales, which cause outages in space-based communication and GPS-based navigation systems.

APPROACH

The day-to-day variability in ionospheric irregularity generation giving rise to equatorial scintillation has remained an unresolved issue over many decades (Basu and Basu, 1985). We take a fresh look at the problem utilizing the global imagery provided by the GUVI instrument on NASA's TIMED satellite. GUVI has been acquiring images of 135.6-nm emission in the Earth's ionosphere/thermosphere system since 2001. These GUVI disk images at dusk have been used to identify cases where the equatorial ionization anomaly (EIA) crests lie nearly at the magnetic equator over a relatively narrow longitude range, so that the anomaly looks collapsed. A 16-month period of evening GUVI data at solar maximum is used to study the morphology of these so called collapses, since the EIA collapse is shown to be linked to the suppression of equatorial bubbles and scintillations. We obtained several dramatic examples of day-to-day variability in EIA behavior and scintillations over India. The SAMI3 model is currently being used to investigate the conditions during the evening collapse of the anomaly in the Indian longitude sector where measurements of total electron content (TEC), scintillations and estimates of the daytime vertical drifts were available using magnetometer measurements.

WORK COMPLETED

The above analysis has been completed and a manuscript is being prepared for publication in the Journal of Geophysical Research. Two presentations on this work were given at the AGU Spring Meeting in Acapulco, Mexico in May 2007 and the COSPAR Scientific Assembly in Montreal, Canada in July 2008.

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14. ABSTRACT
Understanding physical processes that leads to plasma structuring in the equatorial, mid- and highlatitude ionosphere. Identifying the effects of such variability, generally known as ionospheric space weather, on the operation of various communication, navigation and surveillance systems.

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RESULTS

The GUVI instrument is a scanning imaging spectrograph that is sensitive in five emission bands [*Christensen et al.*, 2003]. These emissions have been extensively used for mesospheric and ionospheric studies. In this study, we will concentrate on the nighttime disk images taken of the O I 135.6-nm emission feature. This emission arises from the radiative recombination of atomic oxygen as well as a small contribution from ion-ion mutual neutralization. Neglecting this secondary contribution, its brightness is proportional to the square of the electron density. Thus, it acts as an excellent tracer for the dynamics of the low-latitude nighttime ionosphere on a global scale. As seen in the example composite image of GUVI disk scans in Figure 1, where the emission is mapped to 150 km above the earth's surface, the EIA peaks are clearly visible over a large portion of the globe; they are typically separated by about 15 degrees on either side of the magnetic equator. However, a collapse of the EIA is also clearly visible between 45 and 60 degrees E longitude. On examining consecutive days of GUVI data, it becomes evident that there is a large amount of day-to-day variability in the separation and density of the two peaks. This day-to-day variability appears to have a direct influence on the occurrence of scintillations along trans-ionospheric radio wave links as we shall presently show.

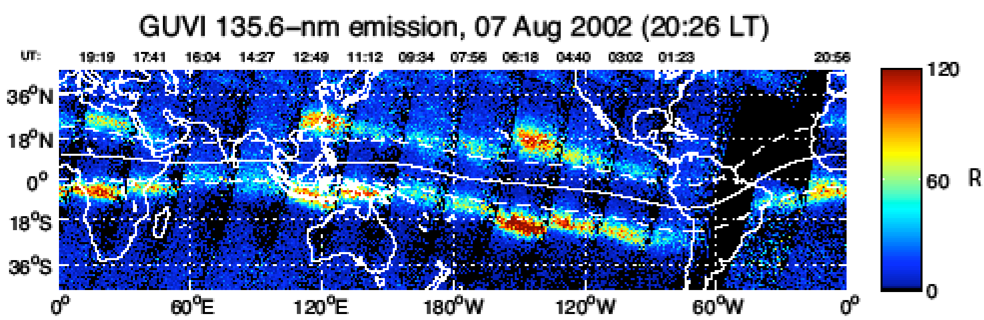

Figure 1. Emission from the 135.6-nm OI radiative recombination line observed by GUVI on 7 August 2002. Disk images are used and radiances have been mapped to a 150-km altitude spheroid to show geographic extent. The times listed along the top are the geomagnetic equator crossing in UT. Longitude is measured in degrees east of Greenwich. The crests of the EIA are clearly visible over the Pacific and Far East; however, they collapse almost completely over the Arabian Sea.

To study the morphology of the occurrence of collapsed EIA crests, we have examined GUVI disk data from 1 February 2002 to 8 June 2003. In order to detect collapses, the data were plotted for each day in a format similar to Figure 1. Collapsed crests were noted visually and recorded. The TIMED spacecraft precesses slowly such that each pass on a given day occurs at approximately the same local time. However, the spacecraft cycles through all local times about every 60 days. For this work, we have concentrated on data collected between 1900 and 2200 LST, due to the relative brightness of the peaks early in the evening compared to later times. This corresponds to 98 days during the 16-month analysis. The dates provide coverage over all seasons and with the near sun-synchronous TIMED orbit, all longitudes were uniformly sampled during these time periods. It is important to note that among the 98 days studied, 43 instances of anomaly collapses were observed on 28 unique days. Thus at least 30 per cent of the days had a collapsed EIA feature as in Figure 1 at some longitude. This work has shown how longitudinally confined these EIA collapses are and the global images provided by GUVI were necessary to establish this feature.

Several instances of fairly dramatic day-to-day variability in anomaly behavior and in the occurrence of scintillation were observed during the 16-month period. We focus our attention on two consecutive days in order to better understand the possible drivers of such variations.

Figure 2 shows the GUVI radiances projected to 150-km for 3 February 2002. This is a fairly typical magnetically quiet day, where the anomaly crests are well separated in all longitude sectors. We shall refer to this as our “typical” day. In contrast, 2 February 2002 shows the occurrence of an EIA collapse over the Indian sector (Figure 4). In the following discussion, this will be referred to as the “collapsed” day. It should be noted that the FUV emissions are much more intense in February (Figures 2 and 4) when compared to the data for August shown in Figure 1. An enlarged version of the GUVI data over India on the typical day is shown in Figure 3g. The GUVI scans look more separated as the data are projected to a height of 350 km (rather than the 150 km projection height seen in Figure 2), the nominal height of the F-peak. Two consecutive orbits from each of DMSP F14 (dashed line) and F15 (solid line) satellites are also shown superimposed on the GUVI data with their magnetic equatorial crossings being shown with white dots. The ionospheric penetration points (IPP) from Calcutta, India and Singapore are shown as yellow diamonds for the VHF channel and as a red dot for the Calcutta GHz channel. The IPP for Calcutta for both channels are at the equatorward edge of the northern anomaly peak whereas that for Singapore is much closer to the magnetic equator but in the southern hemisphere.

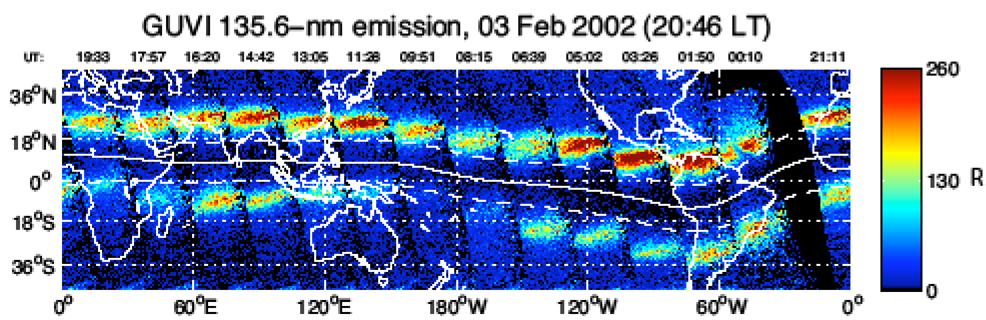

Figure 2. Same as in Figure 1, but for 3 February 2002. This represents a “typical” day with well developed EIA crests globally, but of varying intensities. Note the different scale for the radiances.

To the left of the expanded view are diagrams showing electron density data measured at 840 km from the two DMSP satellites showing the presence of bubbles (Figures 3a-d). The local times for these sun-synchronous satellite orbits are between 20.2-21.3 MLT and agree well with the LT of the GUVI scans between 20:43-20:57. The data in the lowest panel (Figures 3e-f) show saturated scintillations at 250 MHz (S_4>1) and significant 1.5 GHz scintillations at Calcutta whereas Singapore had only 250 MHz data available which shows fairly high scintillation levels. Multiple scintillation structures are seen at both sites. The S_4 index is a quantitative measure of intensity scintillation and is defined as the ratio of the standard deviation of signal intensity fluctuations and the mean signal intensity. Scintillation strength, and therefore the S_4 index, is expected to increase with increasing electron density. Thus, the larger scintillation magnitude seen from Calcutta as compared to Singapore is consistent with the IPP from the former station being located near the high-density EIA peak rather than near the low-density magnetic equator.

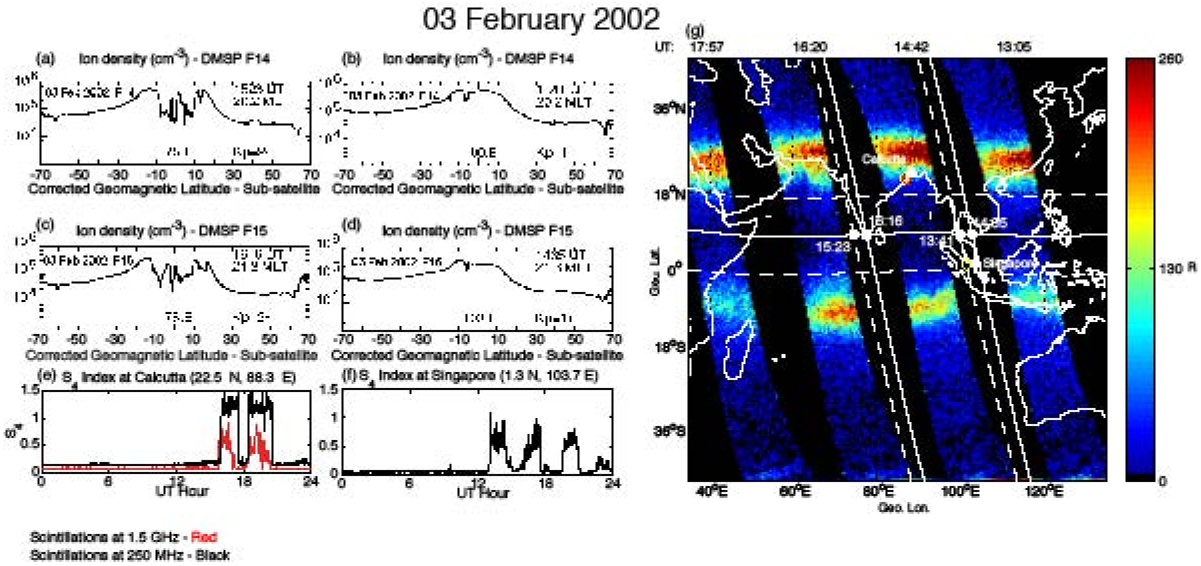

Figure 3. (a) – (d) Two consecutive sets of DMSP F14 and F15 in-situ data of ion densities at 840 km on 3 February 2002 showing the presence of equatorial bubbles. The two orbital tracks are shown in (g). (e) and (f) show the intense scintillations observed at Calcutta and Singapore. The IPP of those measurements are shown in (g) by yellow diamonds for the GHz ray path. (g) shows an enlarged version of Figure 2 between longitudes 45 to 135 degrees but with the radiances mapped to 350 km.

The anomaly characteristic shown in Figures 4 and 5g for the previous day, 2 February 2002, is dramatically different with the two anomaly peaks shown to collapse much closer to the magnetic equator over India. No equatorial bubbles were seen in the DMSP data (Figures 5a-d) and no scintillations (Figures 5e-f) were measured at either of the two stations. The collapse and its impact on the generation of small scale irregularities are quite noteworthy. Also of note is the limited nature of the longitude sector over which the collapse takes place: approximately 30-40 degrees.

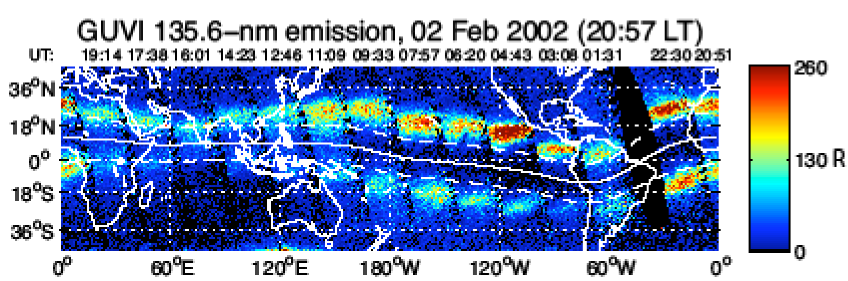

Figure 4. Same as in Figure 2 except for 2 February 2002, which shows a prominent "collapse" of the EIA crests over Indian longitudes. The EIA crests elsewhere are similar to Figure 2 as is the scale for the radiances.

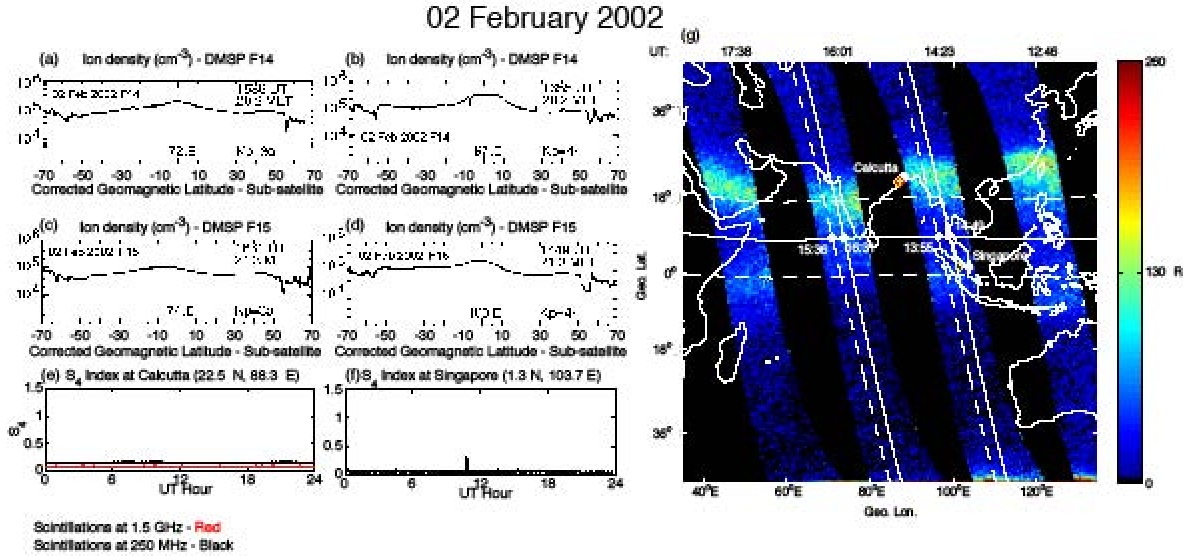

Figure 5. The same as in Figure 3 except for 2 February 2002. Note that there are no bubbles on DMSP data and no scintillations at Calcutta and Singapore.

To investigate this difference in anomaly characteristics, we determined the daytime electrojet strength obtained from magnetometer measurements made by the Indian Institute of Geomagnetism, Mumbai at the two stations Tirunelvelli, on the magnetic equator, and Colaba outside the electrojet region. We used the *Anderson et al.* [2004] technique to convert the Delta H measurement to the vertical **E**×**B** drifts. It is very interesting to note that whereas 3 February is a normal day, 2 February is a counter electrojet day of the type described by *Rastogi* [1973], since the vertical drift changes sign from upward to downward at approximately 1500 LT. Thus it seems that the anomaly collapse at dusk observed in the GUVI data could have been caused by the counter electrojet in the middle of the afternoon. It is quite interesting to note that by studying magnetograms from different equatorial locations around the globe, *Rastogi* [1973] came to the conclusion that counter electrojets are fairly localized in longitude and on some occasions may not occur on the same day at two stations separated by even 2 or 3 hours in longitude. This is consistent with the collapse morphology seen in the GUVI data. It has also been shown from Alouette data that the anomaly does not form in the topside up to 600 km on counter electrojet days [*Alex et al.*, 1987].

Modeling studies using the NRL SAMI2 [*Huba et al.*, 2000] and its 3-D counterpart SAMI3 are being currently conducted to simulate the background conditions with drivers of equatorial electrodynamics to provide a better understanding of the short-term variability in EIA dynamics and its impact on irregularity generation.

IMPACT/APPLICATIONS

The isolation of the drivers of equatorial irregularity generation is of great interest in determining impacts on communication and navigation systems operating in such regions. Considering that the day-to-day variability has remained unresolved for many decades, this fresh look at the problem is expected to be quite fruitful.

RELATED PROJECTS

Two related projects deserve brief mention. The first is the study of the large magnetic storm-induced nighttime ionospheric flows at midlatitudes and their impacts on GPS-based navigation systems. A JGR paper has been completed on this topic with Boston College and AFRL colleagues as coauthors. Other storms that had similar impacts are being investigated and a paper will be presented on this topic at the Fall AGU 2008 Meeting. The second project is related to the COSMIC campaign conducted in the Kwajalein sector in September 2006. Interesting results have been obtained regarding irregularity generation using simultaneous radar, optical and scintillation data with over-flights of the TIP instrument on COSMIC in collaboration with NRL colleagues. These results will be presented at the Fall AGU 2008 Meeting also.

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Basu, Su., S. Basu, J. J. Makela, E. MacKenzie, P. Doherty, J. W. Wright, F. Rich, M. J. Keskinen, R. E. Sheehan, and A. J. Coster, Large magnetic storm-induced nighttime ionospheric flows at midlatitudes and their impacts on GPS-based navigation systems, *J. Geophys. Res.*, 113, A00A06, doi:10.1029/2008JA013076, 2008.

HONORS/AWARDS/PRIZES

Sunanda Basu was invited to deliver a Memorial Lecture on Dr. A. P. Mitra, a very distinguished Past President of URSI, at the opening ceremony of the XXIXth International Scientific Radio Union (URSI) General Assembly in Chicago, IL, USA on 10 August, 2008.